Assessment of cardiovascular reactivity by means of spectral analysis

Mulder, Lambertus Johannes Maria

5 Abstract

The present study on the one hand deals with the spectral methods required for exploring the backgrounds of fluctuations in heart rate (HRV) and other cardiovascular time series. At the other, some applications of the proposed methods in the field of mental workload and stress are discussed.

The model of Wesseling et al. (1985) is adopted as an approach to describe the relations between fluctuations in heart rate, blood pressure and other cardiovascular signals which play a role in short term blood pressure regulation. Starting point with respect to the representation of HRV was Baylys Integral Pulse Frequency Modulator (IPFM) model (1968). Time series of other cardiovascular signals such as systolic and diastolic blood pressure are constructed by deriving such values from beat-to-beat. The time point of the second R-wave in each cardiac interval is then taken as the sample point belonging to that value.

It is argued that spectral analysis is indispensable for untangling the various sources of fluctuations which appear in these cardiovascular time series. For heart rate a spectral analysis method, earlier described by Rompelman (1986), is adopted which is based on a direct fourier transform of the cardiac event series. For other cardiovascular time series, including respiration, a discrete fourier transform method (DFT) is proposed which is closely related to the procedure for HRV. (Chapter 1).

Chapter 2 deals with some indices, and measuring and pre-processing techniques which are required for research on mental workload and stress. A spectral approach applied to beat-to-beat values of various cardiovascular signals is chosen; the following points are noticed:

- Spectral energy measures are defined as integrated spectral density values in pre-defined bands, such as the LOW (0.02-0.06 Hz), MID (0.07-0.14 Hz) and HIGH (0.15-0.50 Hz) frequency band. It is supposed that each frequency area can be differentially affected by task load and stressor variables.
- Heart rate (HR) rather than interval (IBI) spectral variability measures are to be preferred because of the choice of the IPFM-model as a possible generation mechanism for cardiac events.
- A number of arguments is given for using normalized HR spectral variability scores rather than absolute measures.
- The weighted coherence (Porges et. al., 1980) is chosen as an index for corresponding variability between two time series within a selected spectral band.
- Baroreflex sensitivity (BRS) is computed using the modulus of the transfer function of IBI and systolic blood pressure (SBP) changes in the MID and HIGH frequency band.

Additionally, the fact that artefacts in a cardiac event series have serious effects on the computed spectra is discussed. One missing R-wave event in a measuring period of 100 seconds causes as much, or even more, variance as does normal signal variability. Moreover, it is indicated that rhythm disturbances of physiological origin that can occur in normal subjects may have similar effects. It is pointed out, however, that a simple interpolation procedure is adequate for

correction of such errors. Even a series of 8 consecutive missing R-wave events (a 'hole' inserted in an artefact-free original series) does not induce a visible difference between the spectra of the original untreated and the corrected time series.

Chapter 3 deals with the spectral computational technique itself. The way in which spectral functions of heart rate, blood pressure values or other cardiovascular time series can be obtained is discussed. Spectra of HR are computed using the Sparse Discrete Fourier Transform described by Rompelman (1985); for other time series (including IBI) an approach is chosen that can be considered as a computation of the standard discrete fourier transform (DFT) of non-equidistant sampled signals (sampled at time points corresponding with R-wave occurrence time). The fast fourier transform (FFT) cannot be used according to this concept.

Both in the time series of HR and blood pressure a kind of aliasing or sideband effect which is inherently connected to the generation process of these series itself and not to the analysis procedure might occur. This means that difference frequencies of half the mean heart rate and the signal frequency (e.g. a modulating sinusoid) may apppear in the relevant low-frequency part of the spectrum. The ratio of the second sideband amplitude and the main component is proportional to the modulation depth and appears strongest in the upper half of the spectrum. In earlier studies (Rompelman, 1987, De Boer et al., 1985) some of the consequences of choosing a particular method of data representation for heart rate were discussed. In the present chapter additionally some consequences for the interpretation of spectral variability of blood pressure and other cardiovascular signals as well as their mutual dependencies are described.

In particular, differences between spectra of HR and IBI are stressed. The ratio of spectral energy obtained from HR and IBI time series is strongly dependent on mean IBI. This dependency almost disappears when normalized variations (squared modulation index) are considered. Additionally, IBI variability is reduced in the higher frequencies compared to HR variability.

In an appendix to the chapter, the characteristics of the CARSPAN spectral analysis program which is based on this approach, are described. It is argued that the program is suitable for analyzing large data-sets in the same way using a parameter file in which pre-selections of analysis parameters can be stored. Such a method is very adequate in psychological experiments and stress research in which the same analysis has to be repeated on several subjects and subject-groups. An output file structure is chosen which can be used without adaptations in various statistical packages.

In chapter 4 the methods and techniques of chapter 2 and 3 are applied in a number of studies.

In section 4.2 it is argued that both a time- and a frequency-domain approach can be used in order to estimate the dependency between changes in blood pressure

and IBI. The ratio of the amplitudes of these fluctuations is a measure for baroreflex sensitivity. In the time domain, digital filtering is required for selecting those frequencies at which there is a strong correlation between these time series. Additionally, phase correction is necessary for optimal computation of slope and correlation in the regression equation. In the frequency domain the same results can be obtained in a more straightforward manner. This latter approach is therefore advised.

In section 4.3 a paper is included concerning a comparison of results obtained in two experiments with two different subject groups in which identical tasks were performed. In one of the experiments blood pressure is measured intra-arterially; in the other non-invasively at the finger, using the principle of unloading the vascular wall (Penaz, 1973). From both continuously measured signals systolic, diastolic and mean values could be derived from beat-to-beat. In both experiments clear Rest-Task differences are found in the LOW and HIGH frequency band of HR and blood pressure variables. Effects in the MID frequency band are only found in arterial pressure measures and not in finger pressure.
Rest-Task effects on blood pressure level-indices are clearly present in all intra-arterial pressure tiem series (systolic, diastolic, mean), in systolic and mean finger pressure, but absent in diastolic finger pressure. Effects on BRS are similar in both experiments. For all the measures the same pattern of Rest-Task differences can be seen in both experiments. Indications are found which suggest that the power of the finger pressure experiment is less (with respect to blood pressure level-indices) than the intra-arterial experiment: more subjects will be required to obtain similar significance levels. It is concluded, however, that finger pressure measurements, because of its non-invasiveness, can be useful for studying cardiovascular reactivity in stress research.

Section 4.4 contains a paper in which the usefulness of the spectral method for the computation of BRS is studied. Results are obtained using intra-arterial blood pressure measurements. First, spectral BRS indices from a preceding rest (spontaneous fluctuations in blood pressure and heart rate) are compared with those of a few 'vasoactive drug' trials, according to the method of Sleight (1980). Correlation between both methods is 0.94 (n=8), while the average BRS does not differ significantly between the two methods. Spectral BRS values from comparable resting periods correlates highly (0.92, n=12). BRS values during task performance are significantly reduced in two different experimental tasks compared to their preceding rest. It is concluded that the proposed spectral method, when it is combined with finger pressure measurements, can provide us with a useful method for the non-invasive estimation of BRS.

In section 4.5 data from the same experimental session as in the previous study are discussed. Rest-Task differences in HRV, blood pressure variability and BRS were studied during two tasks and its preceding rests: a. a memory search and counting task; b. a mental arithmetic task with noise as a

'memory search and counting' task clear Rest-Task differences are found: a decrease in variability measures of IBI and systolic blood pressure (SBP) in all selected spectral bands; additionally, there is a decrease in mean IBI and an increase of mean SBP as well as a decrease of BRS. Results in the other experiment are less clear cut. On one hand, there is a strong decrease of mean IBI and an increase in mean SBP as well as a clear reduction of BRS in both the MID and the respiratory frequency band. Rest-Task differences are larger than in the experiment on 'memory search and counting'. On the other hand, there are no effects in spectral variability measures in any of the bands. In a more detailed analysis of the time series it is found that five out of the twelve subjects show a respiratory pattern that is comparable to respiration during speaking. Also IBI and SBP variability patterns are comparable. After analyzing the data in two separate groups (speaking, non-speaking), the 'non-speaking' group shows the same pattern of results as is found in the 'memory search and counting' task; the 'speaking' group, however, shows a large increase in IBI and SBP variability in the MID frequency band. BRS does not show this increasing effect. In contrast: for both subject groups the expected decrease in BRS is found.

It is concluded that in both tasks indications are found for parasympathetic withdrawal; the disturbing effect of a speaking-like respiratory pattern in some of the subjects is seen as the reason for contradictory effects in variability.

In an appendix to this chapter a final paper is included in which a simulation approach to study relations between blood pressure, heart rate and other cardiovascular time series is suggested. The model that was chosen for this purpose was presented by Wesseling & Settels (1985). Next to some features of the continuous simulation language to be used (TUTSIM) a number of details are given concerning the implementation of the model-parts and their accessory parameters. It is concluded that simulation could be helpful in order to obtain a better understanding of the role of BRS and sympathetic/parasympathetic control on short term blood pressure regulation.